Published online August 17, 2017

Sensor-based Nitrogen Fertilization for Midseason Rice Production in Southeast Missouri

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Abstract

Sensor-based nitrogen (N) decision management tools have shown potential to improve N fertilizer efficiency, yield, and profitability. Small-plot experiments were conducted to evaluate the use of sensor-based management in guiding midseason N application decisions. Treatments were two rice (*Oryza sativa* L.) cultivars (Jupiter, a medium grain, and Roy J, a long grain) and eight N treatments: (i) check (no N fertilizer); (ii) 60 lb N/acre applied preflood + midseason N applied based on sensor reading (sensor-based management); (iii) 90 lb N/acre applied preflood + midseason N applied based on sensor reading (sensor-based management); (iv) 120 lb N/acre applied preflood; (v) 120 lb N/acre applied preflood + 30 lb N/acre applied at midseason (traditional practice); (vi) 120 lb N/acre applied preflood + midseason N applied based on sensor reading (sensor-based management); (vii) 150 lb N/acre applied preflood; and (viii) 180 lb N/acre applied preflood (N reference strip). Grain yield and nitrogen use efficiency (NUE) were compared among N treatments. Results showed sensor-based management for midseason application recommended lower total N application rate by 15 to 90 lb N/acre over the traditional practice. These results indicate that N fertilization made by a sensor-based midseason recommendation can optimize yield and NUE in southeast Missouri.

The optimal amount of N fertilizer required for rice crops may change dramatically from year to year. This is due to varying level of plant-available N in soil system through N turnovers from N-fixing organisms, mineralization of organic matter in the soil, and decomposition crop residues. In fact, most producers are aware that their yield levels change significantly, but they are not aware that the yield response to additional N changes as well. Nitrogen responsiveness and yield levels dictate precisely how much N should be applied. Thus, what farmers need to embrace is that their NUE changes each year as well.

In southeast Missouri, the common N management practice is to apply most of the N (70– 120 lb N/acre) preflood (Dunn et al., 2008). Then a permanent flood is immediately established. The remaining N is applied based on the plant-N status at midseason. Determining the plant status can be very challenging for producers. To ensure the plant has adequate N to optimize yield, most producers often apply 30 to 45 lb N/acre at midseason via aerial application,

Crop Management

Core Ideas

- Sensor-based N management used with a nitrogen-rich strip was a very effective decision support tool for midseason N management.
- Sensor-based N management provided opportunity to take advantage of year-to-year environmental variation.
- Sensor-based N management approach reduced the amount of total N applied without any yield penalty compared with the traditional practice.

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Received 19 Jan. 2017.
Accepted 8 May 2017.

Abbreviations: BIE, beginning of internode elongation; IE, internode elongation; NDVI, Normalized Difference Vegetative Index; NUE, nitrogen use efficiency; SDNT, spectrally determined nitrogen topdressing.

Conversions: For unit conversions relevant to this article, see Table A.

Published in Crop Forage Turfgrass Manage. Volume 3. doi:10.2134/cftm2017.01.0005

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
53.75	46 lb to bushel per acre, bu/acre	kilogram per hectare, kg/ha
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
0.304	foot, ft	meter, m
2.54	inch	centimeter, cm

which can be costly. However, recent research from the University of Arkansas indicates that newer cultivars do not always respond to midseason N when adequate amount of preflood N have been applied (Norman et al., 2013).

Current approaches suggested for assisting farmers with midseason N fertilization in the upper Delta region are the use of chlorophyll meters (Stevens, 1999) and plant area measurement (Dunn et al., 2008). Research has shown these methods to be capable of providing measurements of crop biochemical characteristics for estimating plant N status. They are often very labor intensive, requiring a large sample size within a field. Research at Oklahoma State University helped develop a sensor-based N management approach utilizing an N-rich strip as a reference strip to provide information on the crop N status (Zhang and Raun, 2006). This approach has led to the development of a functional N fertilizer optimization algorithm that estimates midseason N requirement based on the Normalized Difference Vegetative Index (NDVI) measurements (Raun et al., 2002). The use of a sensor-based N management approach improved NUE, grain yield, and profit when compared with the traditional N rate recommendation (Ortiz-Monasterio and Raun, 2007; Raun et al., 2002, 2005; Tubaña et al., 2008; Xue et al., 2014). Clearly, a sensor-based approach for managing midseason N for rice in the upper Delta region adds an additional tool to the farmer toolbox for addressing the challenge of managing N fertilization.

Therefore, two small-plot experiments were set up to evaluate the use of the GreenSeeker (Ntech Industries, Inc., Ukiah, CA) in guiding midseason N decisions. The result from this study is limited to southeast Missouri, but could have broader application in other rice growing areas. Extrapolation of these results outside of the context of the experiment should be done with caution. Our goal was for these results to be used as a decision support guide to assist producers in working out their own N management strategies within southeast Missouri.

Study Site

Each small-plot field experiment was conducted in 2015 and 2016 at the Missouri Rice Research Farm (36°34′15.04″ N, 90°7′49.12″ W [2015]; 36°34′28.42″ N, 90°7′34.64″ W [2016]) in Glennonville located in southeast Missouri. The soil series for each experiment was an Overcup silt loam (fine, smectitic, thermic Vertic Albaqualf). Average monthly temperature and rainfall were 76.1°F and 20.47 inches from May to September in 2015 and 76.1°F and 19.05 inches for the same period in 2016.

Experimental Design

Crop management practices are summarized in Table 1. The experimental design was a randomized complete block with three replications. Two rice cultivars (Jupiter, a medium grain, and Roy J, a long grain) and eight N treatments were applied to each cultivar. Nitrogen treatments consisted of 0, 60, 90, 120, 150, and 180 lb N/acre as a single preflood application and with or without a midseason application using urea (46–0–0). Table 2 summarizes the N treatments. Plots were established at a seeding rate of 90 lb/acre using a 7-inch-spacing Almaco no-till drill (Almaco, Nevada, IA). Plot sizes were 5 ft wide by 12 ft long in 2015 and increased to 5 ft wide by 20 ft long in 2016. Midseason N was applied at half-inch internode elongation (IE).

Data Collection

Grain yield and NUE were measured and used to evaluate the benefits of using the GreenSeeker sensor-based management approach as a tool for making midseason N decisions compared with the traditional approach of fixed preflood and midseason rates.

GreenSeeker Sensor Data Collection

The GreenSeeker handheld optical reflectance sensor that uses active radiation from red and near-infrared band independent of solar conditions was used for this study. The device has onboard software that calculates NDVI directly at a rate of 10 readings per second. Sensor NDVI readings were collected 23.6 inches above the rice canopy across each plot, and average values were used to represent each plot. Sensor readings were collected at panicle initiation.

Estimating Midseason Nitrogen Using Sensor

Midseason N application was estimated based on the N fertilization optimization algorithm developed by Raun et al. (2002) using the GreenSeeker Handheld Crop Sensor Fertilizer Estimation Chart. Figure 1 outlines the procedure for using the chart. The normalized rate value was obtained by matching the average $NDVI_{ref}$ curve with corresponding $NDVI_{NT}$ on the chart (Fig. 1). The average NDVI of the 180 lb N/acre plots was used to represent the N-rich strip ($NDVI_{ref}$) and the average NDVI of each of the N-treated plots was used as $NDVI_{NT}$. The normalized rate value was multiplied by the crop factor for rice of 233 for a maximum yield of 200 bu/acre to determine the amount of N to apply. Because the sensor readings were similar for the cultivars, $NDVI_{ref}$ and $NDVI_{NT}$ were averaged across cultivars and N treatment. For example,

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Table 1. Characteristics of the experimental plot, cultural practices, date of application, and product applied for the management of the rice crops.

Cultural practice	Date of application 2015	Date of application 2016	Product/cultivar/rate applied
Planting	1 May	28 Apr.	Cultivars: Roy J (long grain) and Jupiter (medium grain) at 90 lb of seed/acre
Harvest	2 Oct.	29 Sept.	
Previous crop	Soybean	Soybean	
Fertilization			
Preflood N	15 June	9 June	N (60–180 lb/acre) applied with 130–390 lb/acre urea
Midseason N	14 July	13 July	N (30–45 lb/acre) applied with 65–98 lb/acre urea
Herbicide			
Preemergence		29 Mar./29 Apr.	Roundup PowerMax (glyphosate) at 26 fl oz/acre + Sharpen (saflufenacil) at 2 fl oz/acre + Invade (methylated seed oil) at 1% (v/v)/Command 3ME (clomazone) at 13 oz/acre
Postemergence		6 June/27 July	Propanil at 3 lb/acre + Bolero (thiobencarb) at 3 pt/acre
Insecticide	27 July	28 July	Karate (lambda-cyhalothrin) at 10 oz/acre

Table 2. Nitrogen (N) application treatments of rice used in the study. Nitrogen fertilizer was applied preflood and at midseason using traditional and sensor-based recommendation.

Treatment	Rate of N applied 2015 Pre-flood†	Mid-season‡	Total N	2016 Pre-flood	Mid-season	Total N
	lb N/acre					
1	0	0	0	0	0	0
2§	60	45	105	60	0	60
3§	90	45	135	90	0	90
4	120	0	0	120	0	120
5¶	120	30	150	120	30	150
6	120	0	120	120	0	120
7	150	0	150	150	0	150
8	180	0	180	180	0	180

† Preflood N applied at five-leaf stage.

‡ Midseason N applied at half-inch internode elongation.

§ Midseason N application determined by sensor-based recommendation.

¶ Traditional practice with a predetermined preflood and midseason N application rate.

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in 2015, $NDVI_{ref}$ = 0.75 and $NDVI_{NT}$ values for 60 and 90 lb N/acre were both 0.6. Using the GreenSeeker Handheld Crop Sensor Fertilizer Estimation Chart, 0.2 was used for the normalized ratio value and 233 for the crop factor, 0.2 × 233 = 46.6 kg N/ha (42 lb N/acre). The 42 lb N/acre was rounded up to 45 lb N/acre, which was applied at half-inch IE to the plots with preflood rates of 60 and 90 lb N/acre (Table 2).

Nitrogen Use Efficiency

Nitrogen use efficiency was computed from the ratio of grain yield and total amount of N fertilizer applied (Eq. [1]):

$$\text{NUE} = \frac{\text{Grain yield}\left(\text{bu/acre}\right)}{\text{Nitrogen applied}\left(\text{lb/acre}\right)} \quad [1]$$

Grain Yield

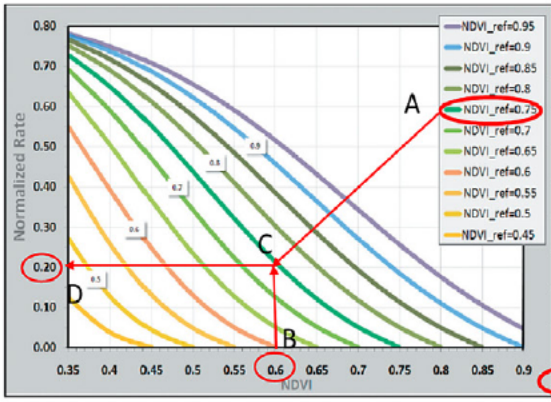
Grain yield was harvested from each plot using Wintersteiger delta combine (Wintersteiger, Salt Lake City, UT). Harvested plot area was 5 ft wide by 12 ft long in 2015 and 5 ft wide by 20 ft long in 2016.

Statistical Analysis

Data were analyzed using the General Linear Model of SAS (SAS Enterprise 9.4, 2016; SAS Institute Inc., Cary, NC), and differences among means were compared using Fisher's Protected LSD procedure at a $P = 0.05$ probability level. Data were presented by year and cultivar to show the year-to-year variation among treatments and between cultivars.

Sensor-based Nitrogen Recommendation

The use of sensor-based N management approach resulted in reduction of total N applied by 15 to 45 lb N/acre in 2015 and 60 to 90 lb N/acre in 2016 compared with the traditional practice (Table 2).



Crop	%N	Maximum yield (kg/ha) 1,000	3,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000	12,000	14,000	16,000
Spring wheat	2.45		134	223	267	312	356	401	445				
Winter wheat	2.30	41.8	69	209	251	293	335	376	418				
Dryland corn	1.30				142	165	189	213	236	260	284	331	
Irrigated corn	1.25					159	182	205	227	250	273	318	364
Barley	1.70	30.9	92.7	155	185	216	247	278	309				
Triticale	2.10	38.2	115	191	229	267	305	344	382				
Sorghum	1.34				146	171	195	219	244	268	292		
Canola	3.10	56.4	169	282	338	395							
Rice	1.28	23.3	69.8	116	140	163	186	209	233	256	279	326	372

Uses NUE = 0.55 and $NDVI_{soil}$ = 0.15

Using the Fertilizer Estimation Chart

Step 1 (A) : Locate the curve closest to value of $NDVI_{ref}$(202 kgha^{-1} plots). $NDVI_{ref}$ = 0.75

Step 2 (B): Locate the value closest to $NDVI_{NT}$ on the bottom axis of the graph. $NDVI_{NT}$ = 0.6

Step 3 (C): Locate where the $NDVI_{NT}$ value intersects with the corresponding $NDVI_{ref}$ curve.

Step 4 (D): Locate the normalize value on the vertical axis that corresponding to the point o where the $NDVI_{NT}$ intersects the $NDVI_{ref}$ curve. Normalize rate = 0.2.

Step 5: Rice was selected in the fertilizer estimation chart table and the maximum yield of 10,000 kgha^{-1}. The crop factor of 233 that corresponds with rice and the maximum yield was selected.

Step 6: Fertilizer rate was estimated by multiplying the normalize rate on the vertical axis on the graph by the crop factor. For example: 0.20 x 233 = 42.6 kg/ha (rounded up to 50 kgha^{-1}).

Fig. 1. Procedure for using the GreenSeeker Handheld Crop Sensor Fertilizer Estimation Chart for estimating mid-season N rate in rice. ac, acre; $NDVI_{ref}$, Normalized Difference Vegetative Index value for the nitrogen-rich strip; $NDVI_{NT}$, Normalized Difference Vegetative Index value for the nitrogen-treated plots; NUE, nitrogen use efficiency. Source: http://www.farmworks.com/files/pdf/GreenSeeker%20HCS/GreenSeeker_FertilizerEstimationChart_91500-01-ENG_Screen.pdf (accessed 6 Mar. 2014).

Grain Yield

2015

Cultivar × N rate did not interact to affect grain yield (Table 3). Grain yield was not affected by cultivar, but N rate did. Thus, the main effect of N rate on grain yield will be presented. The lowest yield was observed from the unfertilized plots; grain yield was significantly lower than all N-fertilized plots. This indicates a positive response to the application of N fertilizer. However, among the fertilized treatments, there were no differences in yield between the traditional practice and the sensor-based management approach. The lowest yield among the fertilized plots was with the 60 lb N/acre preflood application. This was significantly different from the yields of plots with 0, 120, 150, and 180 lb N/acre preflood treatments (Fig. 2). In general, the sensor-based management produced similar yield to the traditional practice, with an average of 30 lb N/acre less.

2016

Similar to 2015, cultivar and N rate did not interact to affect grain yield (Table 3). Grain yield was affected by cultivar and the N rate independently. Thus, the main effect of cultivar and N rate on grain yield will be presented (Table 4). The cultivar Jupiter produced on average 20 bu/acre more grain than Roy J (Fig. 3). Similar to 2015, the lowest grain yield was observed for the unfertilized plots (Fig. 4). However, among the fertilized treatments, there were no differences in yield. As in 2015, the sensor-based management again produced comparable yield to the traditional practice, but with an average of 75 lb N/acre less.

Table 3. Summary of statistical results for treatment effects and interactions for rice cultivars and nitrogen (N) treatments.

Source	Year† 2015 GY	2015 NUE	2016 GY	2016 NUE
Block	NS‡	NS	NS	NS
Cultivar (Cul)	NS	NS	**	***
N treatment (NT)	***	***	*	***
Cul × NT	NS	NS	NS	***
CV	8.7	9.2	4.9	4.3

* Significant at 0.05 probability level.

** Significant at 0.01 probability level.

*** Significant at 0.001 probability level.

† GY, grain yield; NUE, nitrogen use efficiency.

‡ NS, not significant at the 0.05 level.

Nitrogen Use Efficiency

2015

Cultivar × N rate did not interact to affect NUE (Table 3). Nitrogen use efficiency was not affected by cultivar, but N rate did. Thus, the main effect of N rate on NUE will be presented. The highest NUE of 1.7 bu/lb of N applied was achieved with total applied N of 105 and 120 lb N/acre (Fig. 5). In general, sensor-based management resulted in higher NUE compared with the traditional practice.

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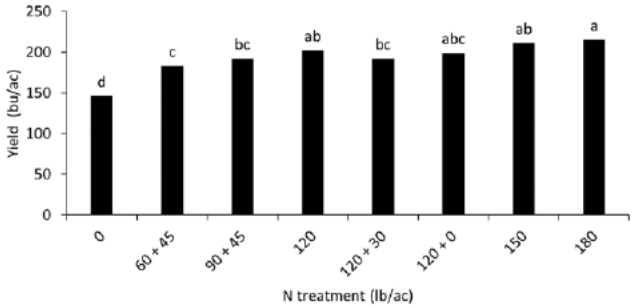

Fig. 2. Yield response of rice to different N treatments in 2015. Treatment 120 + 30 is the traditional practice of 120 lb N/acre preflood followed by 30 lb N/acre midseason application. The 90 + 45, 60 + 45, and 120 + 0 are sensor-based management recommendations for midseason application. Means followed by similar lowercase letters are not significantly different.

2016

Cultivar × N rate interaction effect on NUE was significant (Table 3). Thus, Jupiter (1.6 bu/lb of applied N) produced more grain yield with less N compared with Roy J (1.4 bu/lb of applied N). The highest NUE of 3.0 and 2.5 bu/lb of N applied was achieved with 60 lb N/acre applied N to Jupiter and Roy J, respectively (Fig. 6). Similar to 2015, NUE was higher with the sensor-based management for both Jupiter and Roy J over the traditional practice (Table 4).

Interpretation of Results

In both years of the study, the sensor-based N management reported similar yields and higher NUE over the traditional N management practice. Xue et al. (2014) also found similar results from comparing farmers' N management strategies in China to that of a spectrally determined N topdressing model (SDNT). They reported that the yields of the SDNT strategy were either similar or better with reduced N rates, higher NUE, and superior net profit. Likewise, sensor-based N management for midseason application also increased NUE, grain yield, and net return on rice in Mississippi and Louisiana compared with the traditional split application approach (Tubaña et al., 2011; Xue et al., 2014).

Many farmers in southeast Missouri currently use a single application of preflood N at 100 to 150 lb N/acre to avoid expensive aerial applications of N at midseason (Dunn et al., 2008). These results confirm that this application approach could be maximizing NUE. Most farmers are knowledgeable about the potential for N loss from single application. Single N application program increases the risk of N loss by volatilization from surface application of urea before flooding and denitrification after flooding that could result in lower yields. Compensating for the loss that may occur from the preflood N is the reason many farmers choose to use a split application approach.

Table 4. Grain yield (GY) and nitrogen use efficiency (NUE) of rice by cultivar comparing traditional vs. sensor-based N management. Nitrogen fertilizer was applied preflood and at midseason using traditional and sensor-based recommendation.

Year	Cultivar	Nitrogen rate	Statistics	GY	NUE
		total N (lb/acre)		bu/acre	
2015	Roy J	0		144	–
		120		211	1.8
		120 + 30†		180	1.2
		120 + 0‡		198	1.7
		90 + 45‡		184	1.4
		60 + 45‡		184	1.8
		150		208	1.4
		180		213	1.2
			$LSD_{0.05}$	36	0.3
			CV	11	12.0
	Jupiter	0		149	–
		120		211	1.8
		120 + 30†		203	1.4
		120 + 0‡		200	1.7
		90 + 45‡		200	1.5
		60 + 45‡		181	1.7
		150		214	1.4
		180		216	1.2
			$LSD_{0.05}$	22	0.2
			CV	6	7.0
2016	Roy J	0		147	–
		120		158	1.3
		120 + 30†		164	1.1
		120 + 0‡		150	1.3
		90 + 0‡		159	1.8
		60 + 0‡		149	2.5
		150		154	0.9
		180		159	1.0
			$LSD_{0.05}$	NS§	0.1
			CV	5	4.0
2016	Jupiter	0		155	–
		120		176	1.5
		120 + 30†		176	1.2
		120 + 0‡		182	1.5
		90 + 0‡		177	2.0
		60 + 0‡		177	3.0
		150		175	1.0
		180		175	1.2
			$LSD_{0.05}$	13	0.1
			CV	4	3.0

† Traditional practice with a predetermined preflood and midseason N application rate.

‡ Midseason N application determined by sensor-based recommendation. Total N rate is preflood + midseason, for example, 120 lb N/acre preflood + 30 lb N/acre midseason.

§ NS, not significant.

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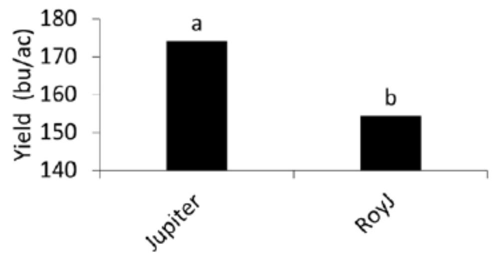

Fig. 3. Grain yield of rice cultivars Jupiter and Roy J in 2016.

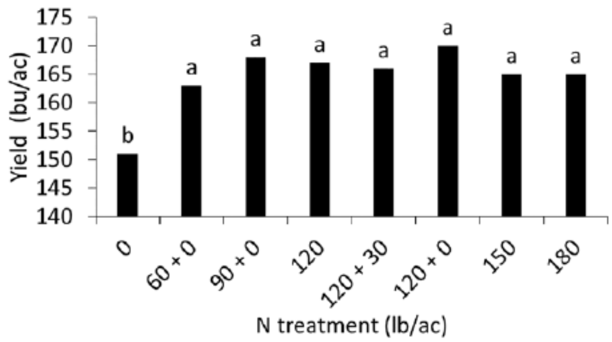

Fig. 4. Yield response of rice to different N treatments in 2016. Treatment 120 + 30 is the traditional practice of 120 lb N/acre preflood followed by 30 lb N/acre midseason application. The 60 + 0, 90 + 0, and 120 + 0 are sensor-based management recommendations for midseason application. Means followed by similar lowercase letters are not significantly different.

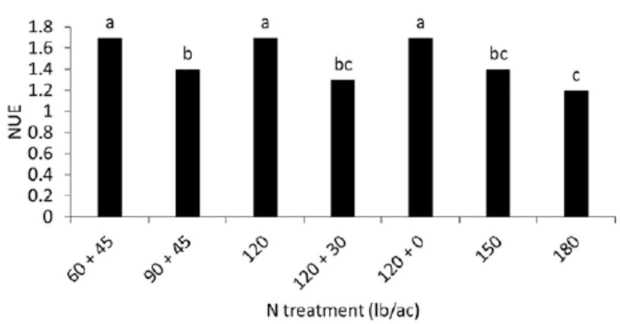

Fig. 5. Nitrogen use efficiency (NUE) of different N treatments of rice in 2015. Treatment 120 + 30 is the traditional practice of 120 lb N/acre preflood followed by 30 lb N/acre midseason application. The 60 + 45, 90 + 45, and 120 + 0 are based on sensor-based management recommendations for midseason application. Means followed by similar lowercase letters are not significantly different.

The results from this study also raise concerns about the benefit from the midseason N application on these cultivars. In both years a single application rate of 120 lb N/acre maximized yield and NUE. The lack of response to midseason N was also a concern for Norman et al. (2013). Norman et al.

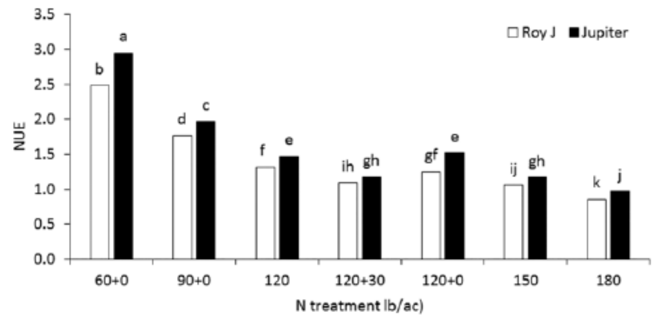

Fig. 6. Nitrogen use efficiency (NUE) of different N treatments by rice cultivar in 2016. Treatment 120 + 30 is the traditional practice of 120 lb N/acre preflood followed by 30 lb N/acre midseason application. The 60 + 0, 90 + 0, and 120 + 0 are sensor-based management recommendations for midseason application. Means followed by similar lowercase letters are not significantly different.

(2013) also found that a single preflood application of 120 lb N/acre application resulted in similar or higher yield than when N was applied in split applications. According to Norman et al. (2013) application of midseason N at the beginning of internode elongation (BIE) or even 7 days after BIE could reduce N uptake and/or impact the grain yield as the rice may be still taking up the preflood N at the time of midseason application. Therefore, delaying the midseason N application beyond the half-inch IE could increase the benefit of the midseason (Norman et al., 2013).

One clear drawback to the sensor-based management approach observed during this study was that it does not provide a starting point for preflood N rate. This could be a challenge for producers deciding to utilize the sensor-based approach. The use of preflood soil sampling for N analysis to determine preflood N rate in combination with the sensor-based approach as a monitoring tool to determine the need for midseason N could offer a solution to this concern.

Implication to Producers

The variation in N requirement and application rates in 2015 and 2016 is evidence demonstrating that sensor-based tool do offer some advantage over the traditional practice to guide midseason N management decision. The advantage of the sensor-based management seems to be the ability to capitalize on environmental variability. For example, in 2015, 120 lb N/acre preflood was required to maximize yield and NUE while in 2016, 60 lb N/acre preflood maximized yield and NUE. This indicates that in 2015 rice crop was more responsive to applied N fertilizer than in 2016. Many factors influence the crop response to N application each year, but N availability to the plant is the most important. The responsiveness of the rice crop could be a result of less plant-available N in 2015 than in 2016. Plant-available N increases in the soil system through N turnovers from N-fixing organisms, mineralization of organic matter in the soil, and decomposition of crop

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residues. Thus, accounting for the amount of free N input and the amount additional N needed to maximize yield and NUE each year are critical.

The results of this study demonstrate that rice N application rate in southeast Missouri could be reduced without any yield reduction. The results of this study seem to suggest that a single preflood application of 120 lb N/acre was enough to maximize yield without the additional cost involved with midseason application. However, this realization only came about as a result of comparing the traditional practice with the sensor-based decision management support. The sensor-based approach functioned more like a litmus paper test, providing a response for a midseason application.

The findings of this study suggest that lowering preflood N rates to 60 to 90 lb N/acre with sensor-based monitoring for midseason could fully optimize yield and NUE. In addition, the results show a strong indication that a single 120 lb N/acre preflood also maximized yield and NUE. The simplicity of this approach might will be more attractive to producers. However, even with the single 120 lb N/acre preflood approach, to take advantage of the environmental conditions that differ every year the use of sensor-based management decision support tool may be warranted. Nitrogen management is complex. The variation in the rice crop responsiveness to N fertilization in 2015 and 2016 was evident due to environmental variation from year to year.

Conclusions

Sensor-based decision support management approach reduced the amount of total N applied, increasing NUE while producing similar yield to the traditional practice. Application of 60 to 90 lb N/acre preflood in combination with sensor-based approach optimized grain yield and NUE. These results suggest that sensor-based management can be improved by determining the appropriate preflood N rate and identifying the appropriate timing for midseason N. In addition, if there is a need to delay midseason N application beyond BIE, sensor-based N management could be used in determining the best timing for a midseason application. Additional long-term research is needed in this area.

Acknowledgments

We want to express a sincere thanks to Missouri Rice and Merchandising Council for providing the funding for this project. We also want to express our heartfelt appreciation to Chad Mikeal for assistance with plot management and harvesting, and to Blake Gray of KOCH Agronomic Services, LLC for providing the fertilizer for this study.

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Printed by [ACSESS - 074.195.227.186 - /doi/epdf/10.2134/cftm2017.01.0005] at [09/11/2020].